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ROTATING-MACHINERY POWER SUPPLY FOR LONG-RANGE SONAR

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INTRODUCTION

Sonar systems used by the Navy in World War II employed frequencies in the range of thirty kilocycles per second at a power level of approximately ten kilowatts. Since this time, use has been made of progressively lower frequencies, higher power levels, and longer pulse durations.

The power levels and duty cycles being considered for new developments are such that shipboard power supplies cannot deliver adequate power to the transducer driver without interfering with other loads being supplied. This necessitates the use of energy storage systems or completely self-contained power supplies.

The requirements of such a power source for long-range sonar were established as follows:

(1) Generated Frequency - 5000 cycles per second adjustable within a range of plus or minus 250 cycles per second and controlled to an accuracy of plus or minus one cycle per second.

(2) Output Voltage - 2000 volts single phase.

(3) Transient Response - Frequency shall be stabilized to within the allowed steady-state deviation within one second after step application of full load. Voltage shall be stabilized to within 90% of steady-state value within one second after application of full load.

(4) Generated Waveform - Distortion factor less than 10% measured at transducer.

(5) Output Power - 40 kilowatts at unity power factor load.

(6) Duty Cycle - Eight seconds, three seconds full load, five seconds no load.

(7) Load Switching - A suitable switch shall be provided for switching full load power.

An interim report covering selection of a power source and prime mover for shipboard use concluded that a Diesel engine-alternator combination supplying power directly to drive the transducer was best suited for this application.[1] Therefore, a rotating machinery power supply was developed which has precise control of Diesel speed to obtain the desired frequency stability and supplementary control of alternator output to obtain the desired load cycle.

[1] NRL Memorandum Report No. 1, Confidential, dtd 29 February 1952

DESCRIPTION OF POWER SUPPLY

The power supply includes a Diesel engine, an inductor alternator, an electromechanical speed regulator, and an alternator control equipment. In addition, an instrument for precise comparison of generated frequency with an input reference frequency is included and is described in Appendix A.

Figure 1 is a block diagram of this power supply. Diesel speed is regulated by a controller which obtains its actuating signal from an indirect comparison of Diesel speed and the reference frequency. The reference frequency is equal to that desired from the alternator. The alternator output is supplied to the load through a saturable reactor switch and a power transformer. The saturable reactor switch is energized in response to a control signal received from the sonar programming unit. Figure 2 is a photograph of the complete power supply as assembled in the laboratory. Figure 3 is a photograph of the control racks with covers removed.

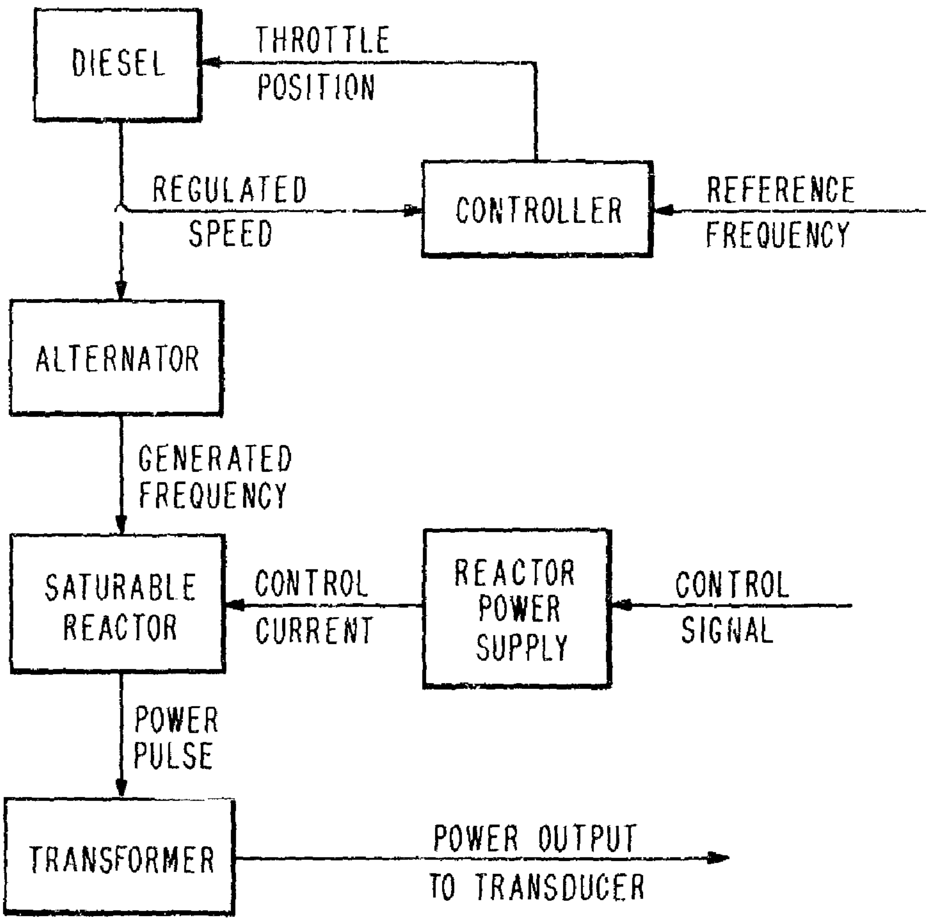


Fig. 1 - LRS rotating machinery power supply

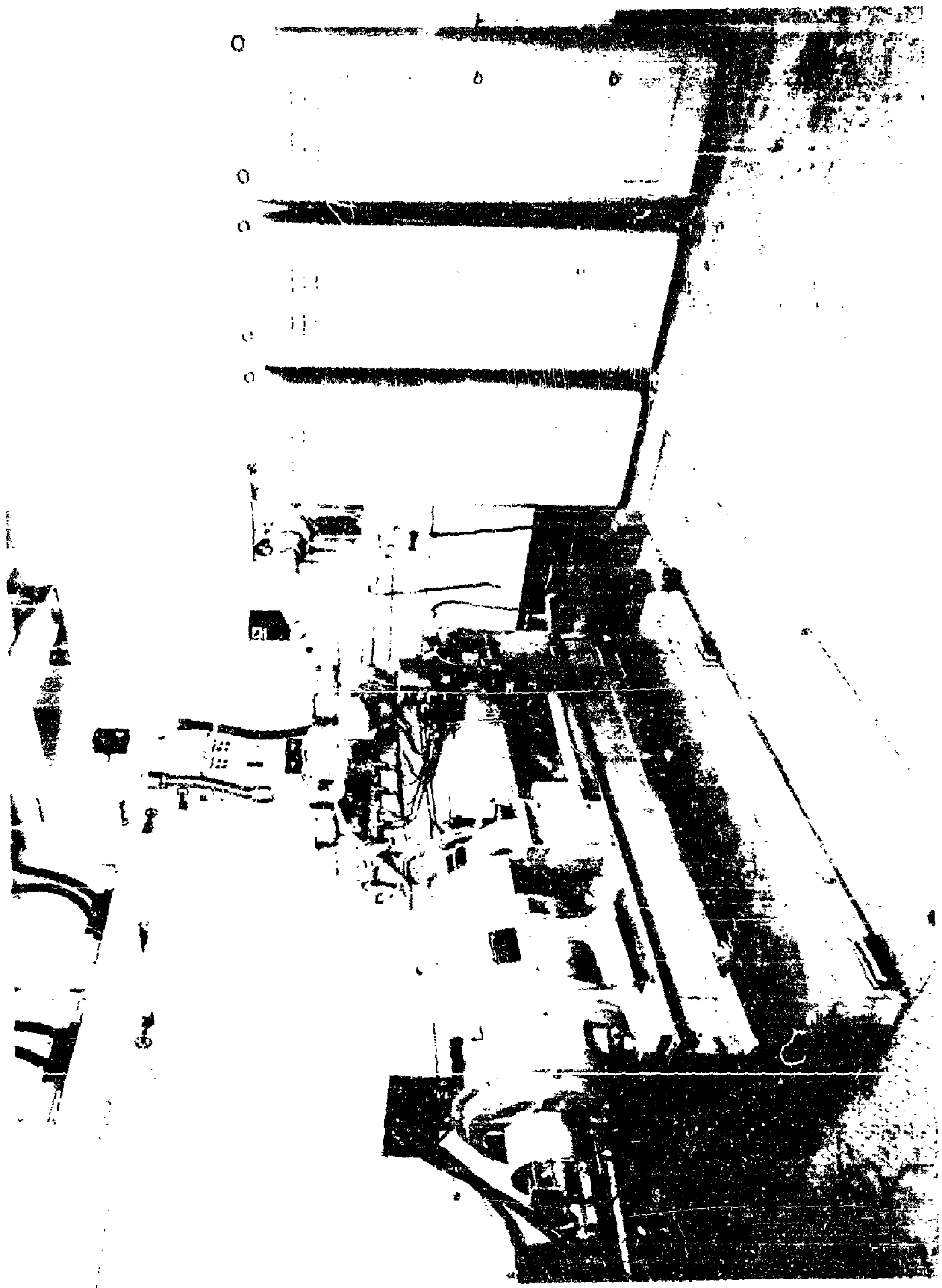


Fig. 2 - LRS rotating machinery power supply

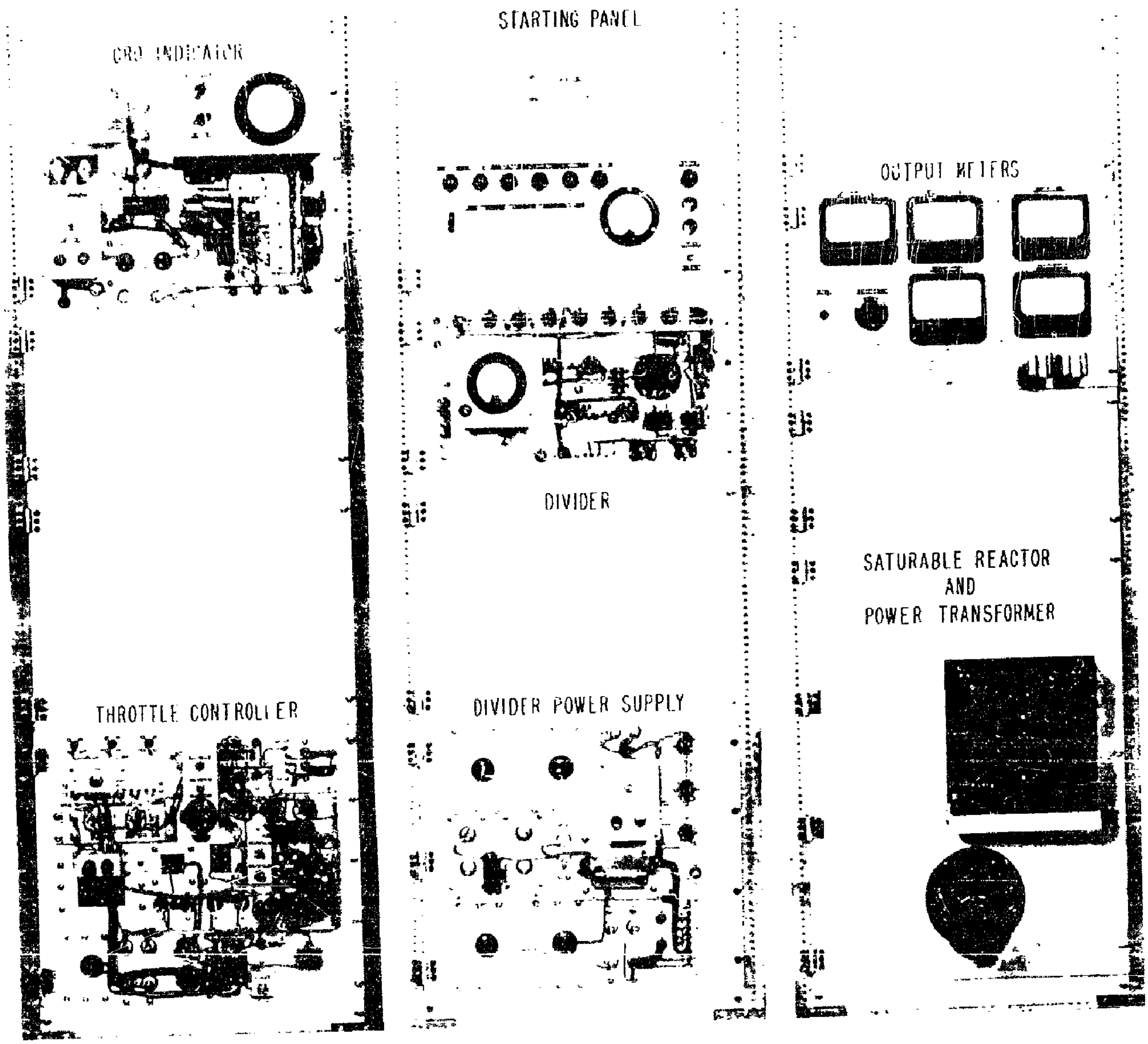


Fig. 3 - Control panels

PRIME MOVER

Several Diesel engines were considered among those having suitable speed and power for driving the alternator. The characteristics of the Diesels considered, along with certain pertinent information, are presented in Table 1. Of this group, a Navy Type DD engine was selected after an over-all consideration of availability, ruggedness, and proven reliability for naval service. This engine is supplied with a water circulating pump, a fuel transfer system, a battery-charging generator, and an electric starter. The clutch and reverse gearing, which are used for boat propulsion, were removed and the flywheel was modified to accept a flexible coupling.

TABLE 1
Diesel Engine Characteristics

Name	No. of Cylinders	No. of Cycles	Maximum Speed (rpm)	Maximum HP	HP at 1800 rpm	Length (inches)	Width (inches)	Height (inches)	Weight (lbs)	Fuel Consumption lb/BHP Hr (1800 rpm)	Type of Injection System
Buda 6 DTS-468	6	4	2500	129	106	48	29	40	1565	0.45	Bosch
Caterpillar D 318	6	4	1800	105	105	76	31	56	3100	0.44	Caterpillar
Continental RD 572	6	4	2000	121	115	52	29	42	1845	0.44	Bosch
Cummins NH-600	6	4	2200	175	150	61	25	49	2435	0.39	Cummins
GM 3061A	3	2	2000	100	96	52	31	45	1680	0.45	GM
Gray Marine 6-D427	6	4	2200	105	95	46	30	36	1350	0.48	Bosch
Hercules DWXLD	6	4	2600	120	96	44	26	41	1350	0.43	Bosch or Roosa Master
Navy DD	6	4	2100	119	112	58	29	39	1600	0.45	Ex-Cell-O Model A
Waukesha 135-DKB	6	4	2800	130	100	47	25	35	1386	0.45	Bosch

The type of engine selected and its fuel injection system determines to a large extent the choice of control equipment. Therefore, the characteristics of the ungoverned engine will be considered before discussing the speed regulator.

All modern high-speed Diesel engines have solid fuel injection systems which place the liquid fuel under extremely high pressure and force it through a spray nozzle into the combustion chamber. The torque developed by the engine is approximately proportional to the quantity of fuel injected per stroke. The selection of a fuel-injection system best suited for this application requires several factors be taken into consideration, namely: (1) amenability to control, (2) consistency and reliability of fuel injection, (3) simplicity, and (4) integration with protective and starting equipment. Two types of injection systems that met these requirements were used in the development of the control. The two systems, Ex-Cell-O and Roosa-Master, which will be discussed in detail, gave satisfactory performance.

The Ex-Cell-O fuel pump illustrated in Fig. 4 is a six-cylinder pump with one cylinder for each engine cylinder. The plungers associated with these cylinders are located circumferentially about a central rotor valve and are driven longitudinally by ball-ended tappets engaging with a swash plate. The swash plate is rotated by the drive shaft, which is geared to the engine crankshaft. Fuel is supplied under low pressure to the six cylinders in sequency by a fuel transfer pump through bypass ports drilled radially from the rotor valve chamber. These ports are then closed in sequence by the trapezoidal land on the rotor valve as each plunger executes its delivery stroke. The axial position of the rotor valve, for manual operation, results from the angular rotation of the control lever in accordance with throttle position. The position of the land determines the portion of the stroke during which oil is forced under high pressure past spring-loaded check valves to the respective engine cylinders. Thus the quantity of fuel delivered each stroke to the injection nozzle is varied by the axial position of the rotating central valve. Equality of the quantities of fuel delivered to each of the injection nozzles is insured since the bypass ports lie in a plane perpendicular to the axis of the rotor valve so that the land closes each of the ports for an equal angular rotation of the rotor. Timing the fuel injections with respect to the engine crankshaft rotation is accomplished by varying the angular relation between the swash plate driving the plungers and the central valve.

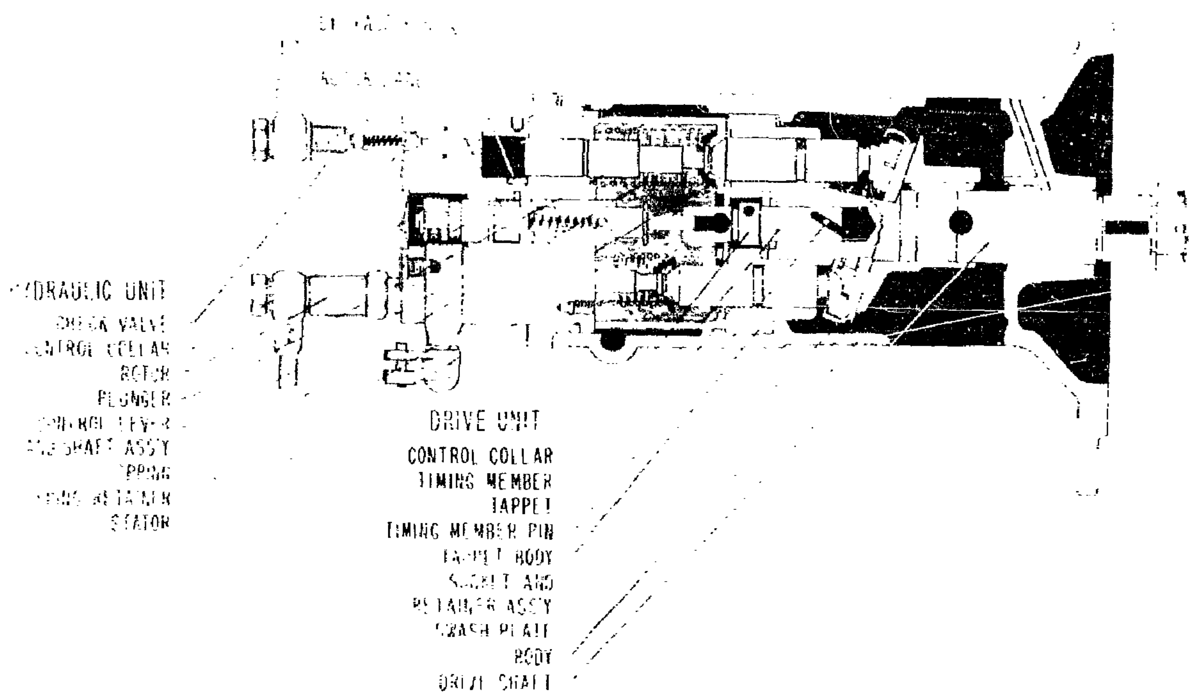


Fig. 4 - Ex-Cell-O fuel pump

The Ex-Cell-O fuel pump requires a governor for stable operation of the Diesel engine because the quantity of fuel delivered per injection stroke is proportional only to throttle displacement and is independent of engine speed. If it is noted that torque is proportional to fuel injected per revolution of the engine which, in turn, is proportional to throttle position, and that the total fuel injected per unit of time (power) is proportional to the engine speed, it will be observed that the Diesel can run at any speed over a wide range for a given throttle setting and constant load torque. To illustrate further, assume a throttle position giving sufficient engine torque to surpass load, windage, and friction requirements; engine speed will increase, thus delivering more fuel per unit time which causes engine speed to increase further. Conversely, a throttle position which does not give sufficient engine torque to overcome load and losses will cause the engine speed to decrease and ultimately the engine will stall.

The Roosa-Master fuel pump, illustrated in Fig. 5, is a single-cylinder, variable-displacement pump. Dual pump plungers are housed in a rotor driven by a shaft geared to the engine crankshaft, and lie in a plane perpendicular to the axis of this shaft; both plungers are driven radially by lift cams on the pump body. Fuel is delivered to these plungers under constant pressure from a regulated supply pump and a metering valve. The metering valve has a flow characteristic proportional to either the angular rotation or the axial displacement of the valve stem. The metered fuel flows through charging passages of a rotating distributor to displace the pump plungers. The quantity of fuel delivered during charging of the pump cylinder is proportional to the flow through the meter valve and the time for which the charging passages are aligned (i.e., inversely proportional to engine speed). Fuel injection occurs when a discharge passage in the rotating distributor is aligned with an injection-nozzle line. Alignment occurs during maximum compression of the pump plungers by the fixed lift cams. Timing the fuel injections with respect to engine crankshaft rotation can be accomplished only by changing the angular alignment of the fuel pump drive gear.

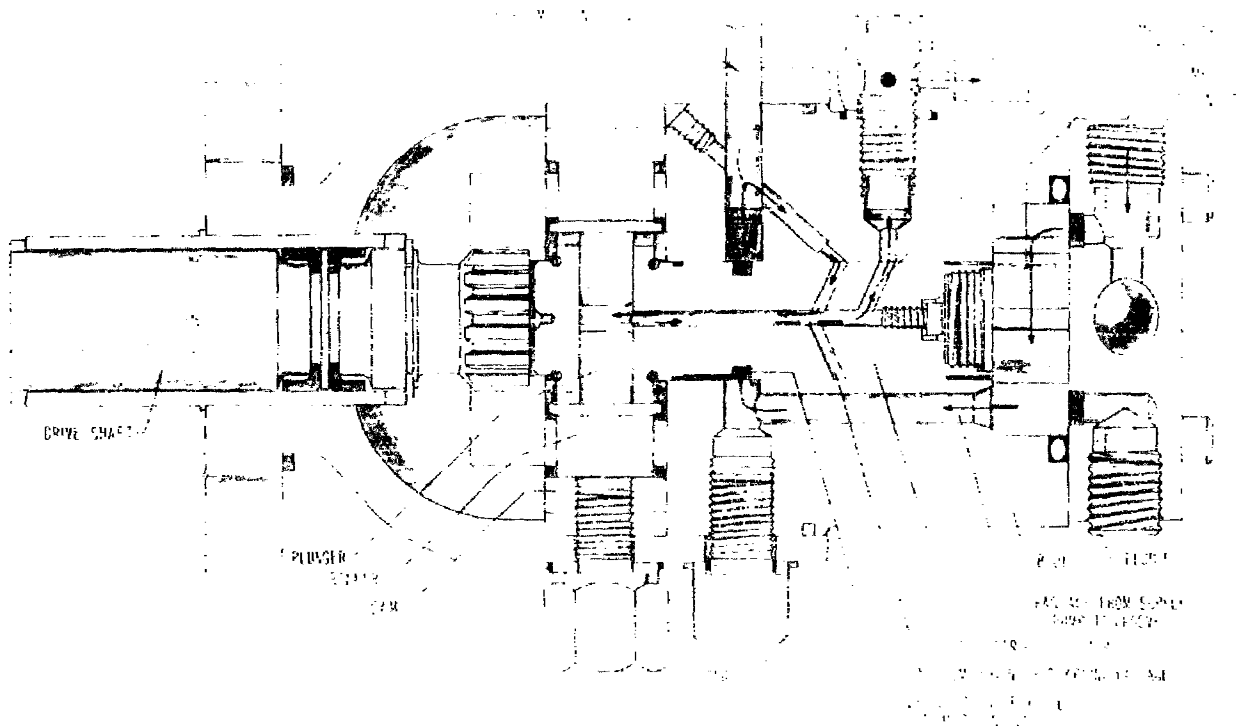


Fig. 5 - Roosa-Master fuel pump

The Roosa-Master fuel pump has self-governing properties because the fuel delivered per injection stroke is proportional to throttle position and inversely proportional to speed. Thus, a throttle position giving sufficient engine torque to overcome load and losses will again cause engine speed to increase, but the fuel delivered per injection stroke will decrease until a balance is reached.

Diesel speed controls were developed for both of these fuel pumps and each gave acceptable performance. It was noted, however, that with the Roosa-Master pump, control was sluggish for a cold engine and that transient duration upon application of load was greater than with the Ex-Cell-O pump. It also was determined that the Roosa-Master could not deliver the maximum power obtained by the Ex-Cell-O pump. Automatic control of the throttle member of the Ex-Cell-O pump required that the mechanical governor be disconnected and a mechanism provided for translatory positioning of the rotating valve, which would have minimum lost motion and would disconnect in the event of a casualty. This protection is inherent in the Roosa-Master pump, which has a solenoid-operated throttle shutoff. In addition, the mechanical governor of this pump provides overspeed protection and operates to rotate the metering valve to the off position independent of the translatory position of the valve resulting from automatic control. A hand throttle is provided so that the mechanical governor may be used for manual operation.

The Ex-Cell-O fuel pump is standard equipment with the Navy DD engine and is thus presumed to have proven reliability. However, the Roosa-Master pump was tested at the United States Naval Engineering Experiment Station, Annapolis, Maryland,[2] and was considered acceptable for naval service. The Roosa-Master pump is simpler in design than the Ex-Cell-O pump, thus reducing maintenance difficulties. After consideration of these factors, it was decided the Roosa Master fuel pump should be incorporated in the final design of the power supply.

PRIME MOVER CONTROLS

Generation of the required electrical power first involves precise control of Diesel speed and then control of alternator electrical output. Since these controls are independent they will be described separately. The method of Diesel speed control is shown by the block diagram of Fig. 6. The controlled variable (Diesel speed) is determined by construction of the alternator. Since the machine is homopolar and has 168 poles the alternator's driven speed in revolutions per second equals the reference frequency in cycles per second divided by 168 cycles per revolution. In the diagram, reference frequency is converted to a reference speed which is compared with Diesel speed to obtain a measure of speed error. A minor servo loop positions the Diesel throttle in response to a composite speed error signal, thus causing Diesel speed to synchronize with the reference speed.

Actually, the reference speed exists only as a rotating flux vector induced by two-phase excitation of the stator of a synchronous motor. The stator is energized through slip rings and is mechanically attached to the alternator shaft. Thus, if the flux vector and the stator frame rotate in opposite sense, the motor rotor will have an angular velocity corresponding to the difference which is system speed error.

The motor is four-pole construction which requires that reference frequency be divided by a factor of 84. Division is obtained by a train of nine binary counters, I through IX as shown in Fig. 7. Nonbinary count-down is obtained by feedback paths from counters

[2]E.E.S. Report 2A101782, Unclassified, dtd 8 August 1952

V and VII to nullify operation of III and II, respectively, and feedforward paths from I and II to reset VII and V, respectively. This arrangement causes a division by 84 rather than the normal 2^8 or 256.

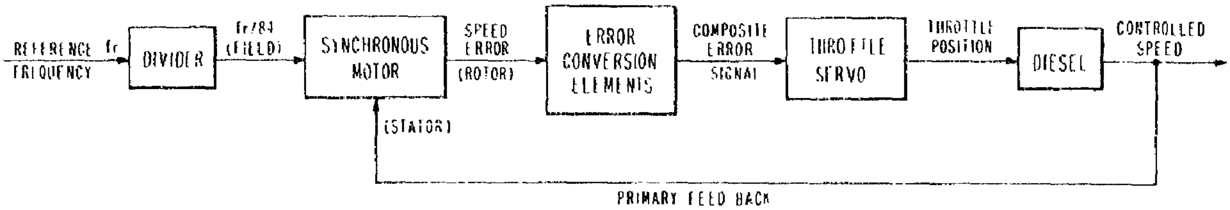


Fig. 6 - Diesel speed control

Operation of the circuit is illustrated with reference to Fig. 8, which shows the waveforms at the plates of the various counters. Counter I is used as a Schmidt switch to obtain pulses from the sinusoidal reference frequency. Starting from zero time in Fig. 8 and for the first eight cycles of the reference, II through V operate in the usual binary fashion. On the ninth cycle the transition of II is used to reset V to its first position and the negative transition of V is used both to nullify the input to III and to cause VI to operate. The operation of II through V again progresses in binary fashion from cycles 9 through 18. On the nineteenth cycle the same operation occurs as on the ninth, causing V to reset and III to remain quiescent. At this time V causes VI to operate, thus operating VII. On the twentieth cycle the transition of I is used to reset VII and the transition of VII is used to nullify the input to II. The twenty-first cycle of the reference sets II to the same position as at time equals zero and the above sequence is repeated. VIII and IX operate in binary fashion to increase the frequency division from twenty-one to eighty-four. The operation of VII through IX is shown with a compressed time scale.

The output of IX (Fig. 7) is fed through a cathode follower to a bandpass filter. This filter passes, with negligible attenuation, the frequencies obtained when the reference is varied over the desired range. The signal, after filtering, is converted to a push-pull signal through a cathodyne phase inverter. The signal then passes through three stages of push-pull amplification. Feedback around the entire amplifier reduces output impedance. The output is transformer-coupled to the synchronous motor. Quadrature relationship between stator windings is obtained by a phase-shifting condenser. The stator is energized through slip rings and is rotated at Diesel speed. As has been indicated, the motor rotor has an angular velocity proportional to the speed error, since the rotating flux vector and the mechanical rotation of the stator are in opposite sense.

The error-conversion elements are an induction generator and a single-turn potentiometer driven from the rotor of the synchronous motor. These provide two electrical signals; one is proportional to the speed error and the other to the integral of speed error. The use of a potentiometer, however, requires mechanical stops to limit angular rotation of the rotor shaft. The diagram of Fig. 9 shows details of the error-conversion and throttle-servo circuits. Here, the proportional and integral signals are summed to provide a measure of desired throttle position which is compared with a feedback signal corresponding to actual throttle position to obtain throttle position error. A manually adjusted bias is combined with the above signals to position the integral potentiometer within the limits of the mechanical stops during normal operation. The signals are summed in the 6AU6 adding amplifier which is followed by the 6C4 impedance-matching amplifier. Transformer 0-8 and the 750-ohm resistor and 1.0-mf capacitor shift the phase of the composite error

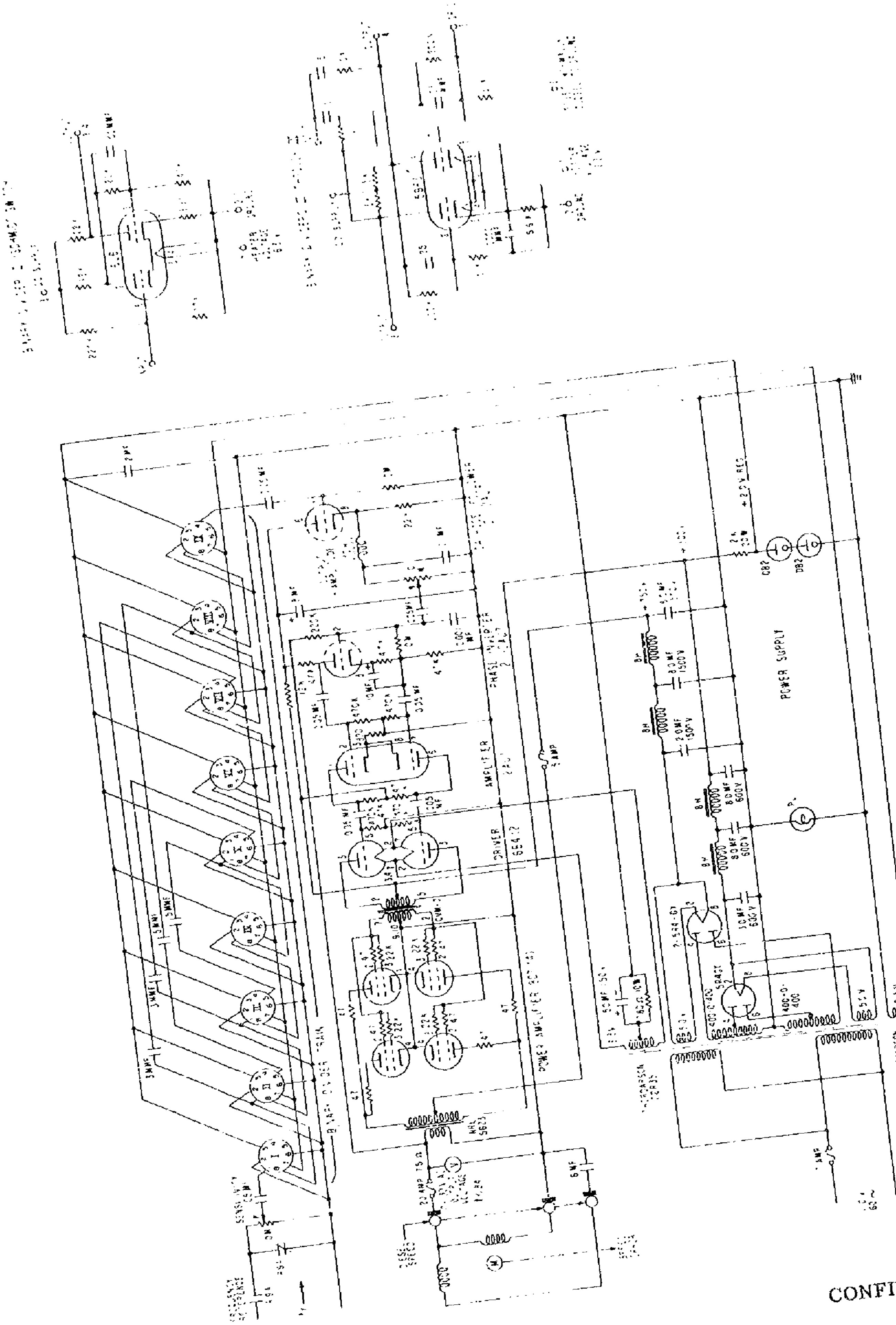


Fig. 7 - Speed reference circuits

signal so that a quadrature phase relationship will exist between the field excitations for the servo motor. The twin-T equalizer serves to stabilize the servomechanism by injecting phase lead in the over-all loop gain characteristic. The twin-T alone has an attenuation of greater than 55 db at 60 cps. The 12AX7 is a two-tube paraphase amplifier driving the 12AT7 push-pull amplifier, which, in turn, drives the two 6L6's supplying the servo motor control field. The control field of the servo motor operates directly from the plates of the 6L6's. An eccentric ball bearing converts servo-motor rotation to translatory motion of the throttle metering valve. The power supply for the servoamplifier is electronically regulated at 350 volts. The 6X4 supplies -105 volts for the bias supply for the 6L6's.

The sensitivities of the proportional and integral signals may be adjusted by the "proportional gain" and "integral gain" potentiometers. Too large or too small a value of proportional sensitivity will result in unstable operation. Integral sensitivity should be adjusted to the highest value consistent with stable operation under load. The "integral adjust" potentiometer is adjusted under no-load conditions until the synchronous-motor rotor is close to the counterclockwise stop. Final adjustment of these settings is made while observing the response of the system to application and removal of load as observed by the pattern presented by the oscilloscope indicator.

Photographs of the speed-control components are shown in Figs. 10 through 14. Figure 10 shows front and rear views of the frequency divider chassis. The reference motor and error conversion elements are shown assembled in Fig. 11 and in exploded view in Fig. 12. Front and rear views of the servoamplifier chassis are shown in Fig. 13 and Fig. 14 is a view of the fuel pump and throttle servo motor showing the eccentric ball bearing which positions the throttle metering valve and the follow-up potentiometer which is driven from the opposite shaft extension of the motor.

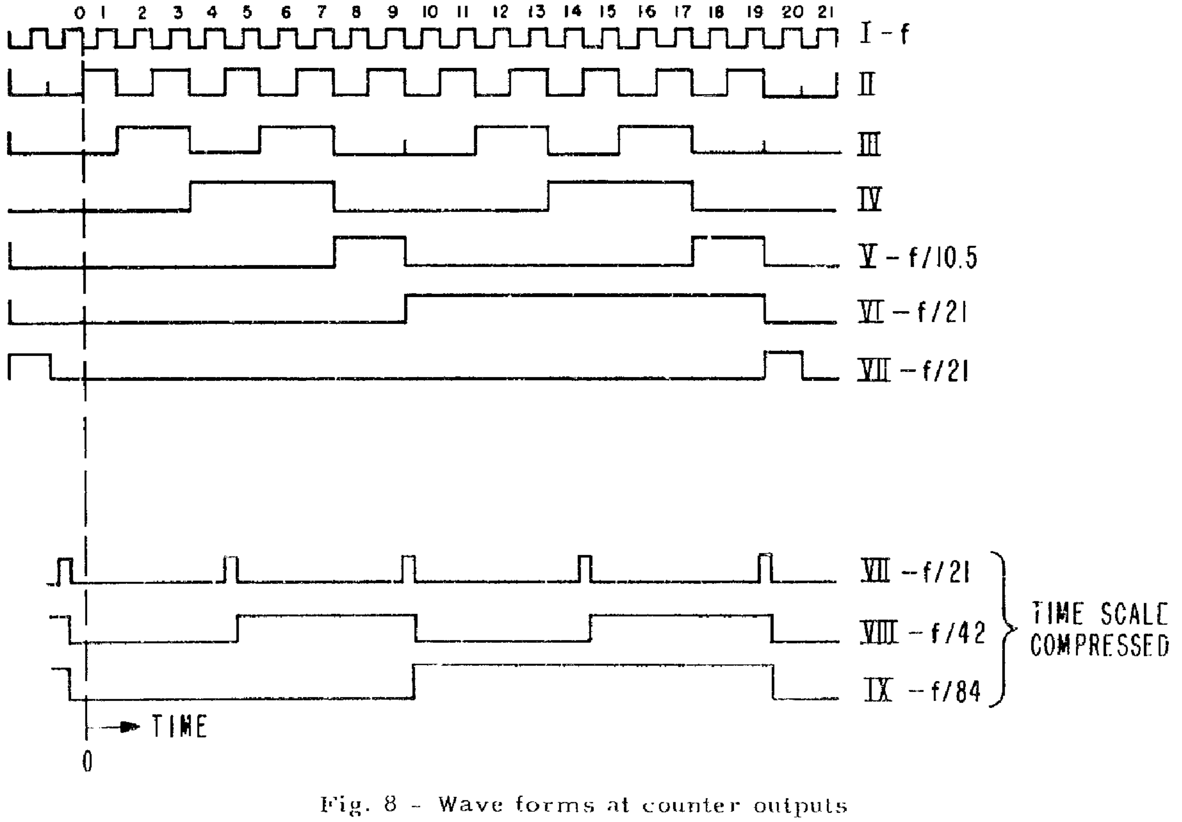


Fig. 8 - Wave forms at counter outputs

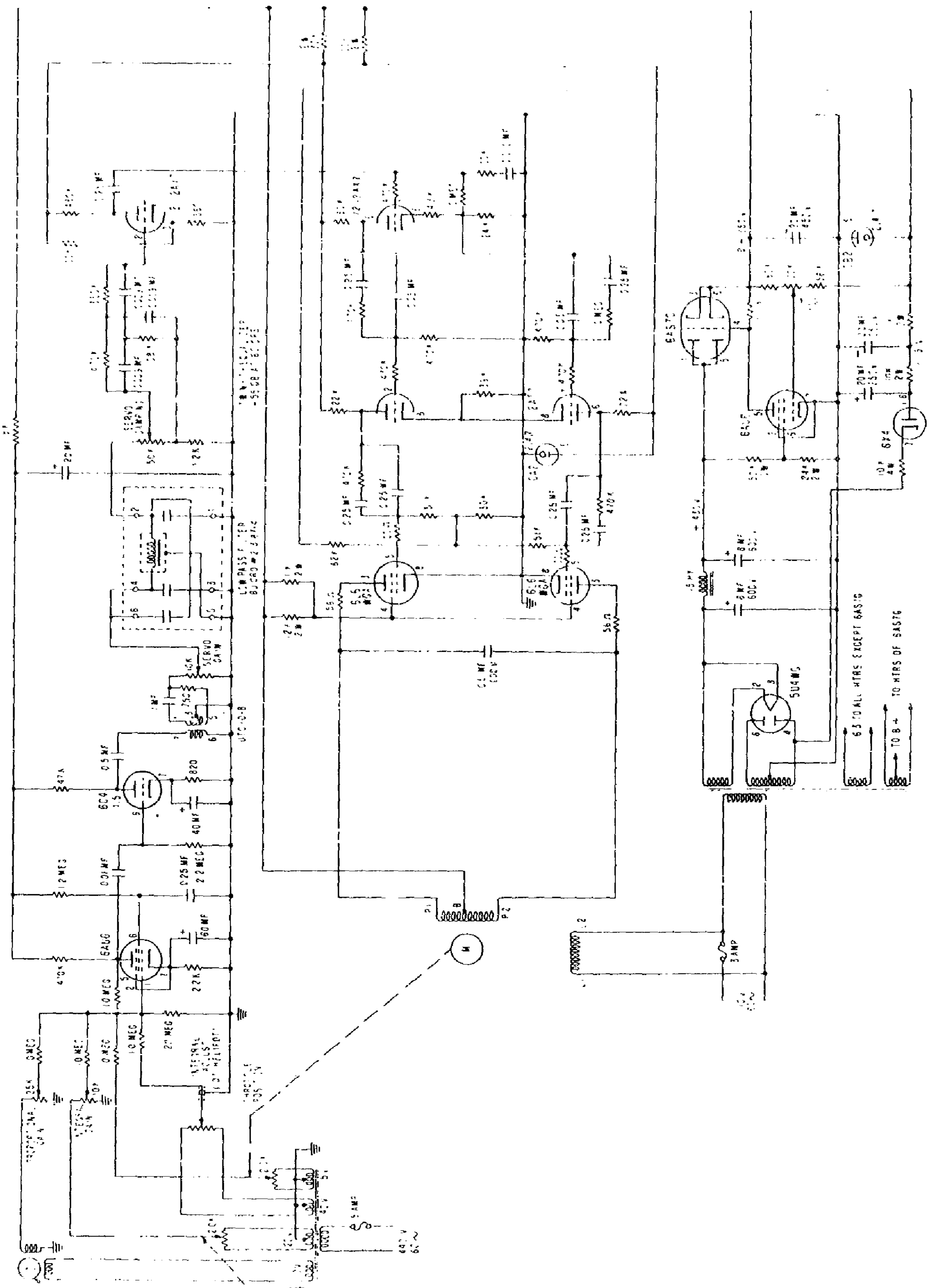
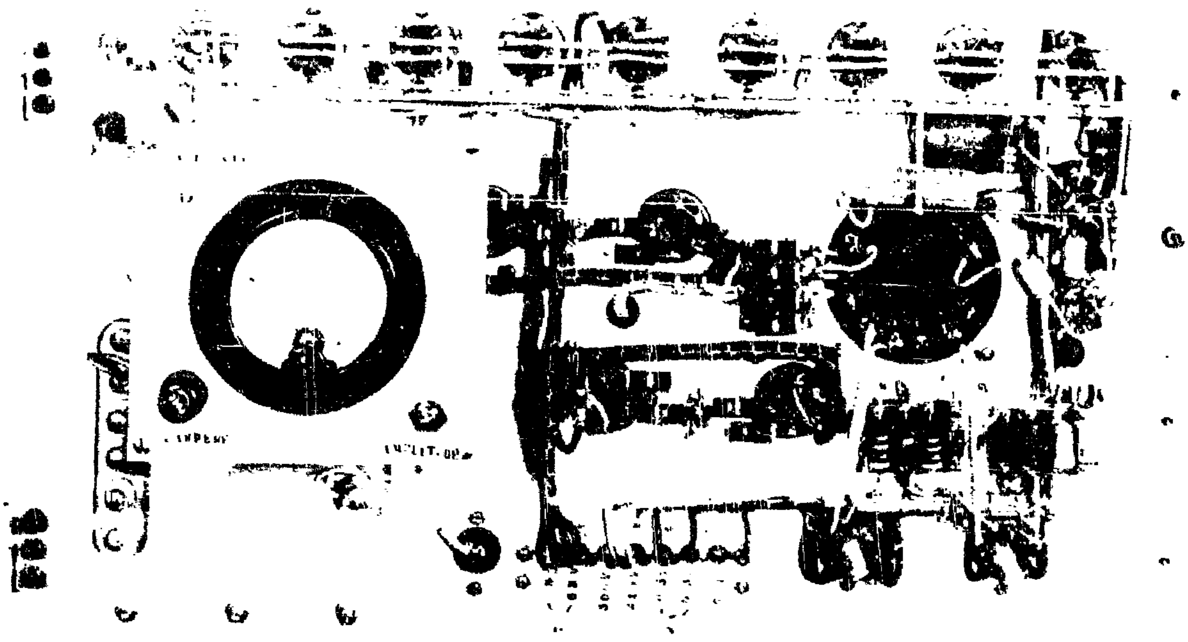


Fig. 9 - Error-conversion and throttle-servo circuits



FRONT VIEW

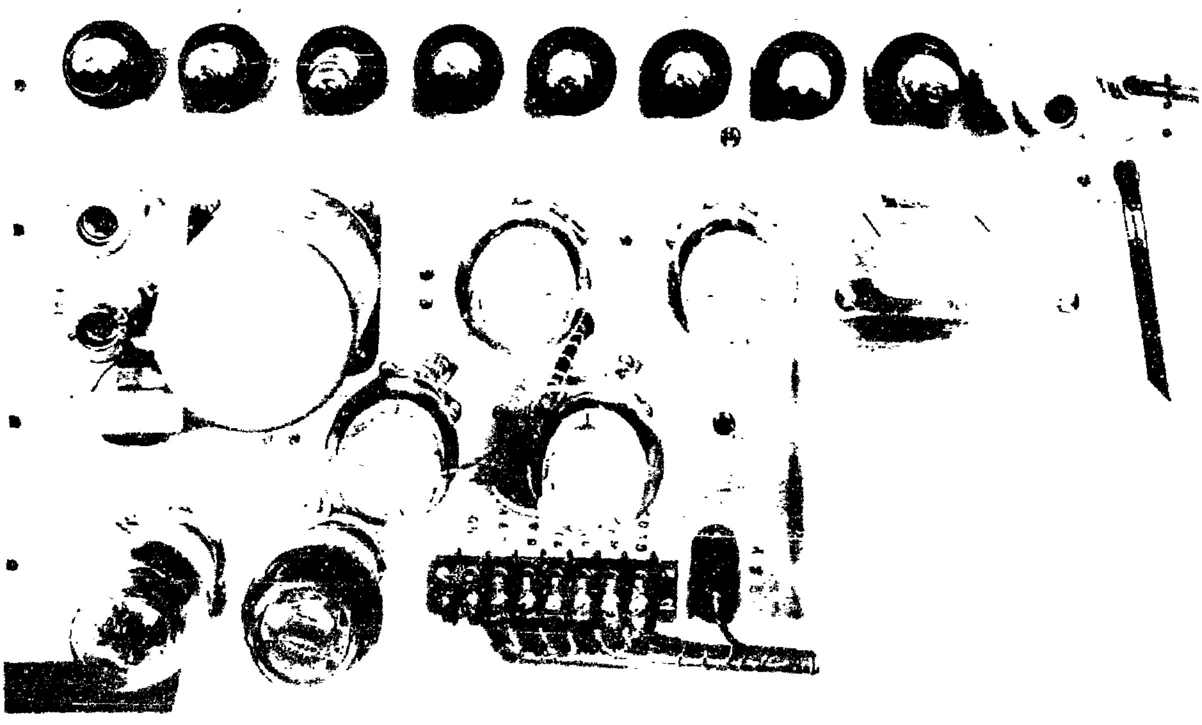


Fig. 10 - Frequency divider (front and rear views)

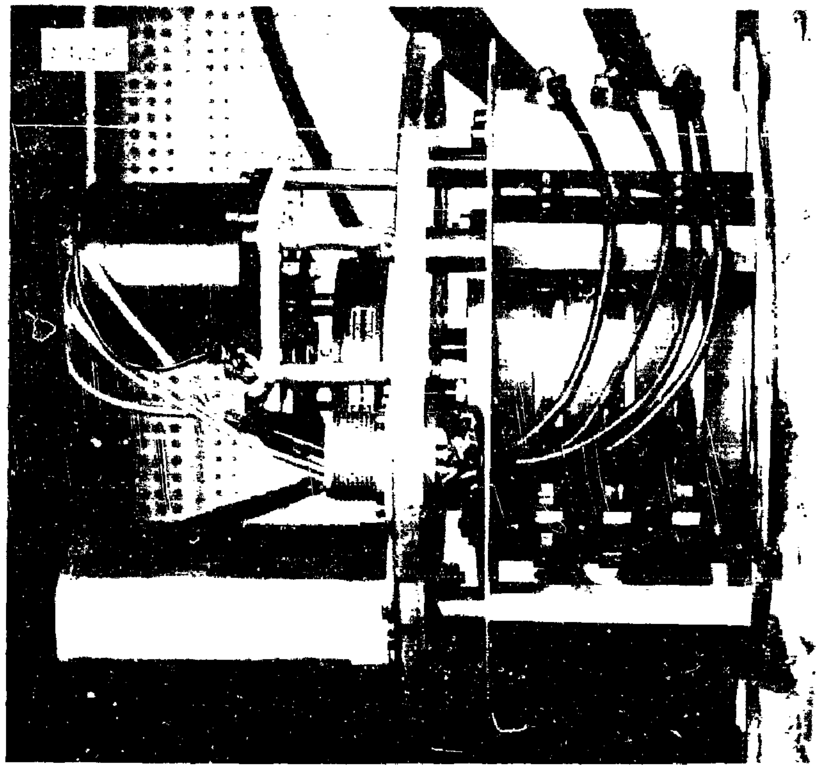


Fig. 11 - Reference motor and error-conversion elements

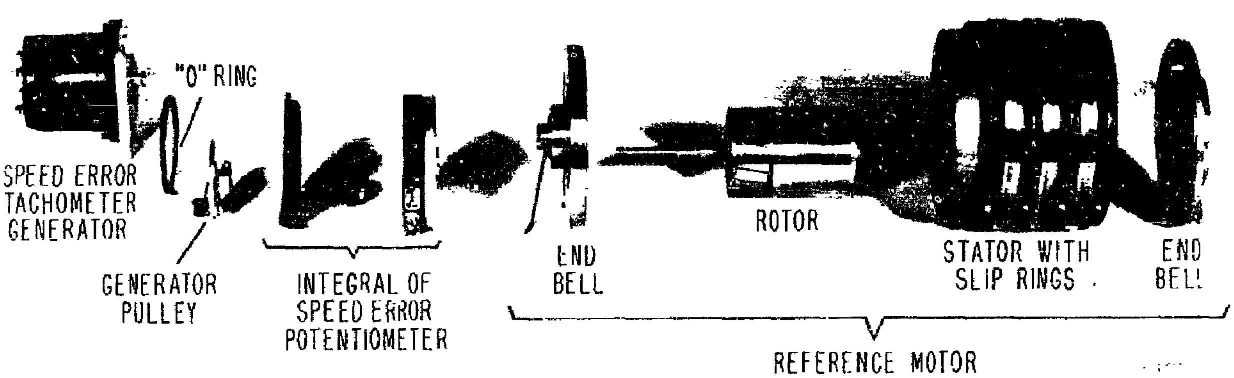


Fig. 12 - Reference motor and error-conversion elements (exploded view)

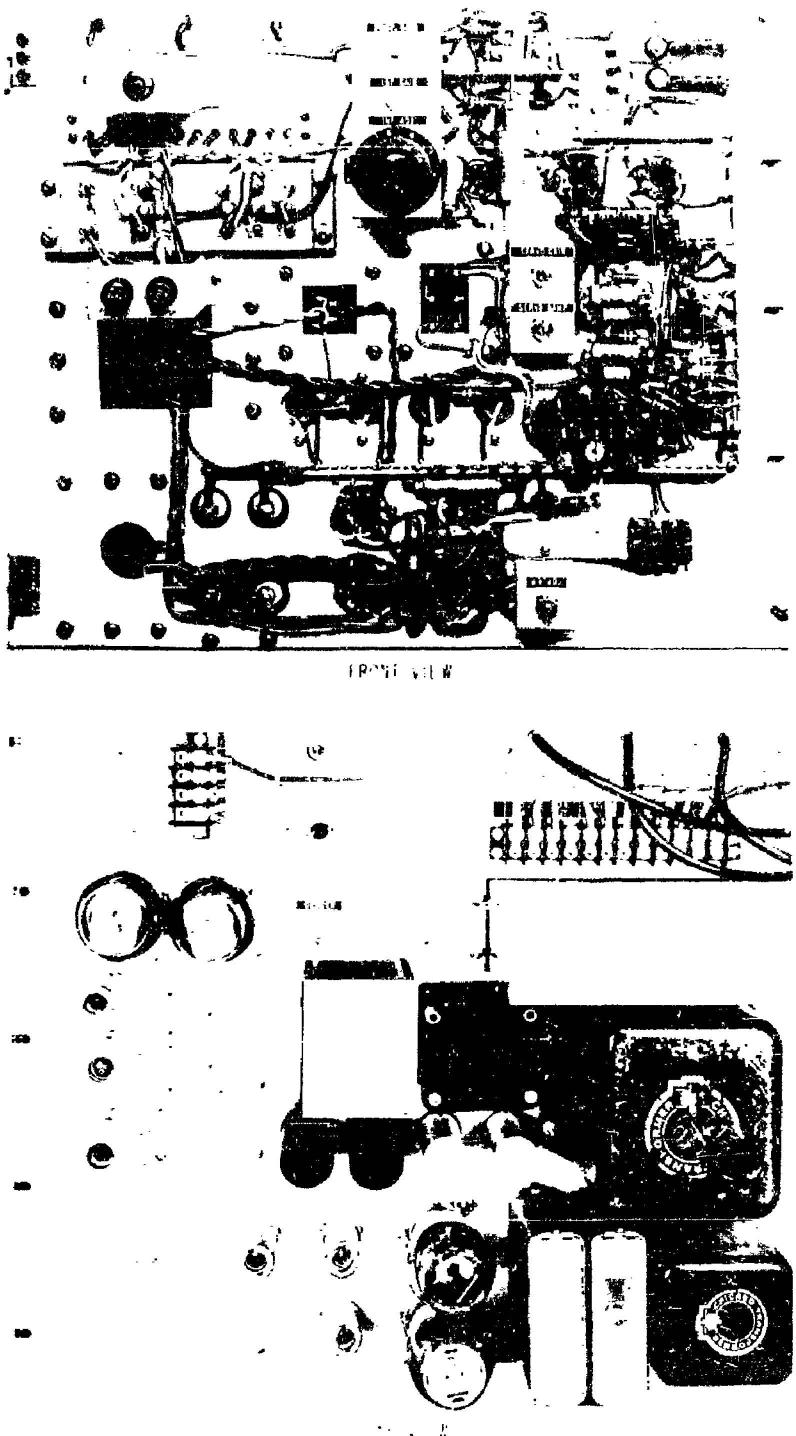


Fig. 13 - Servoamplifier (front and rear views)

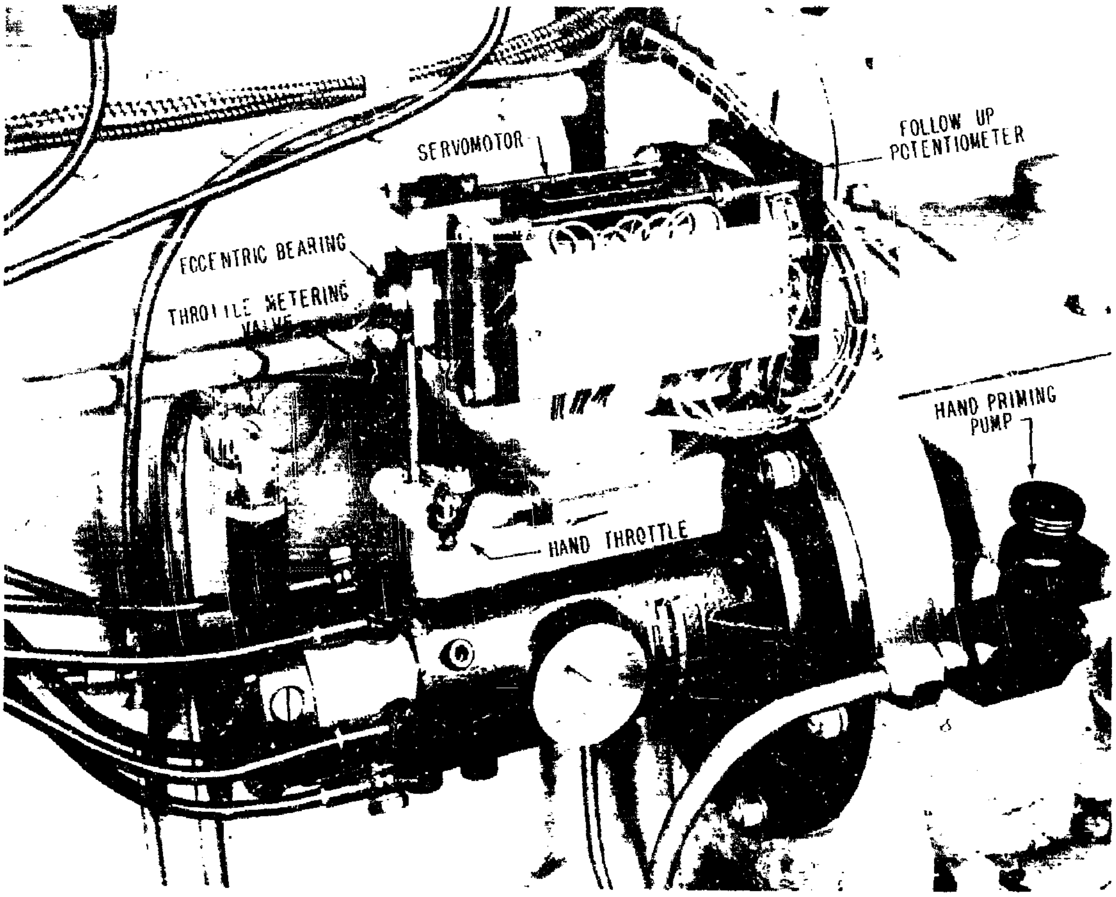


Fig. 14 - Throttle servo and fuel pump

During development of this speed control, various alternative methods of error detection and conversion were considered. The resulting system is closely integrated with the requirements of the sonar system; however, the speed control is applicable to general-purpose power generation.

Both desired speed and desired load cycles are fixed by operating procedure for the sonar system. Therefore, utilization of open-loop compensation to relieve the burden on the closed-loop portion of the rotating-machinery power supply is possible since load pulse duration and magnitude are known prior to load application. Such utilization of the predictable duty cycle would permit greater closed-loop damping to provide reduced steady-state error and improved transient response. First consideration of control methods included utilization of such external compensating means; however, as the closed-loop control system developed, it became apparent that satisfactory transient and steady-state performance would be obtained without recourse to open-cycle throttle manipulations.

Error detection was considered on the basis of both speed and frequency comparison. The former was selected, since direct generation of independent proportional and integral signals is possible. The chosen electromechanical components provide high signal-to-noise discrimination without addition of unfavorable dynamical contributions to the regulatory loop. However, an electronic frequency comparitor was developed which had a resolution of 0.1-volt dc per cycle per second of frequency error over a limited frequency range. The bandwidth was sufficient to have maintained synchronization upon application of load but would have required additional instrumentation to obtain synchronization upon starting. The required integral contribution for the electronic error detector must be obtained by indirect means; unfortunately, this tends towards reduced system stability resulting from the unfavorable characteristics of an integrator. Utilization of the d-c signal to control a hydraulic servo for throttle manipulation was considered since the amplifier power requirements are considerably less and translatory motion of the throttle metering valve is obtained directly. Pseudo integration of throttle position can be obtained by hydraulic means; however, considerable development work would have been required to instrument this method of control.

ALTERNATOR AND CONTROLS

The alternator for which the Diesel and associated controls were selected is an inductor type manufactured by the Ohio Crankshaft Company, Cleveland, Ohio. This unit is the alternator portion of a motor-alternator set normally rated at 30 kw, 3600 rpm, 200 volts and used for induction heating. Figure 15 reveals the general features of construction, showing the split frame, with single field coil and the two a-c coils used in homopolar construction. Cooling is provided by an internal fan and partially open end bells. Approximately 800 cfm of air are required for adequate cooling. The electrical characteristics of this machine for 1800-rpm operation are presented in a separate report.[3]

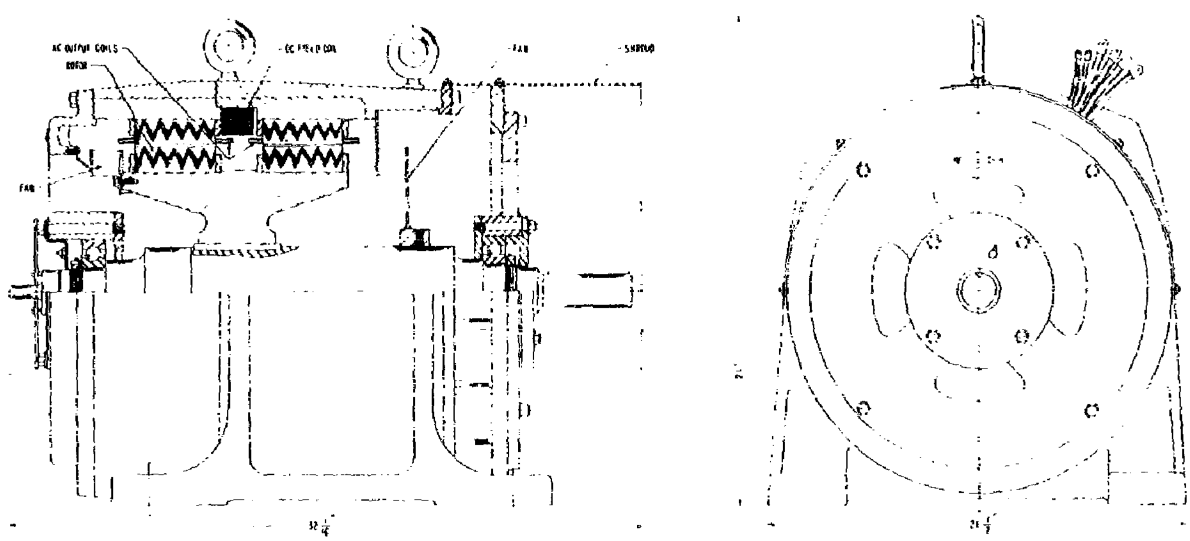


Fig. 15 - Alternator (sectional view)

[3]NRL Memorandum Report No. 26, Confidential, dtd 28 May 1952

The output of the inductor alternator is supplied to the output terminals of the power supply through a series capacitor, saturable reactor switch, and power transformer, as illustrated in Fig. 16. The series capacitance is a General Electric Type 19F63 rated at 230 kva, 220 volts, 9600 cps. This unit has 6 taps, which provide a maximum of 80 microfarads. The primary purpose of the capacitance is to compensate for the effect of armature reactance in the alternator; but is also used in this installation to correct for inductance in the switch, transformer, and load.

The switch in the output power circuit is a saturable-reactor type and is shown in Fig. 17. The general features of this reactor along with the design procedure is outlined in a separate report.[4] Modifications were made, however, in the final unit; these changes are shown in Table 2. The switch offers an impedance of 300 ohms to 320 volts across the a-c coil and zero d-c excitation. This is reduced to approximately one ohm impedance with 20 amperes d-c excitation. The power loss is approximately 500 watts when passing 200 amperes to the load. Excitation requirements are 20 amperes at 20 volts. Response time is less than 50 milliseconds. The power supply for the saturable reactor is shown in Fig. 18.

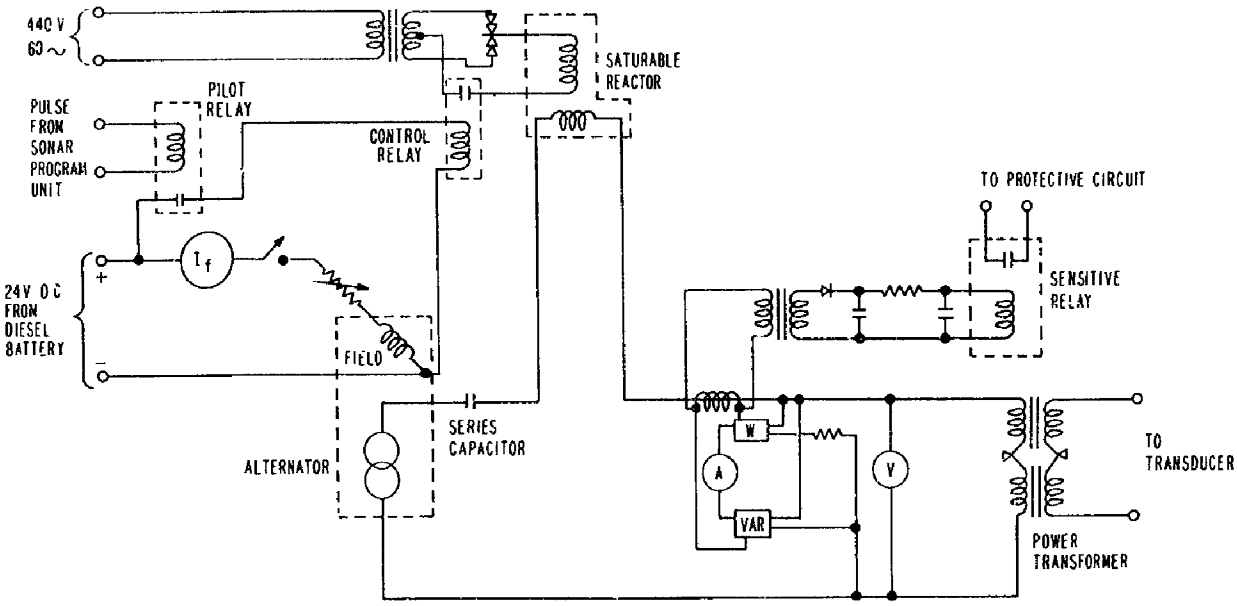


Fig. 16 - Alternator and control circuits

[4] NRL Memorandum Report No. 68, Confidential, dtd 5 Sept. 1952

Fig. 17 - Saturable reactor (top view)

TABLE 2
Five-kc Saturable Reactor Switch Design Data

Core

Material: 1 mil Supermalloy
Two Cores Required
Each Core:
I. D. = 3.75″
O. D. = 5.25″
H. = 1.5″

A. C. Winding

24 Turns on each core connected in series.
Wire Size: Four .045″ x .185″ straps in parallel
Insulation: Class C

D. C. Winding

300 Turns (common to both cores)
Wire Size: No. 11
Insulation: Class A (Double Formex)

Mounting:

Box (open at each end) with square cross section.
8-1/2″ x 8-1/2″, 9″ high.

Total Weight:

33 lb

The output power transformer is of special design consisting of two series-connected units each rated at 95 volts 210 amperes primary, 1000 volts 20 amperes secondary. The detailed description of the design, construction, and characteristics of this transformer, shown in Fig. 19, are presented in a separate report.[5]

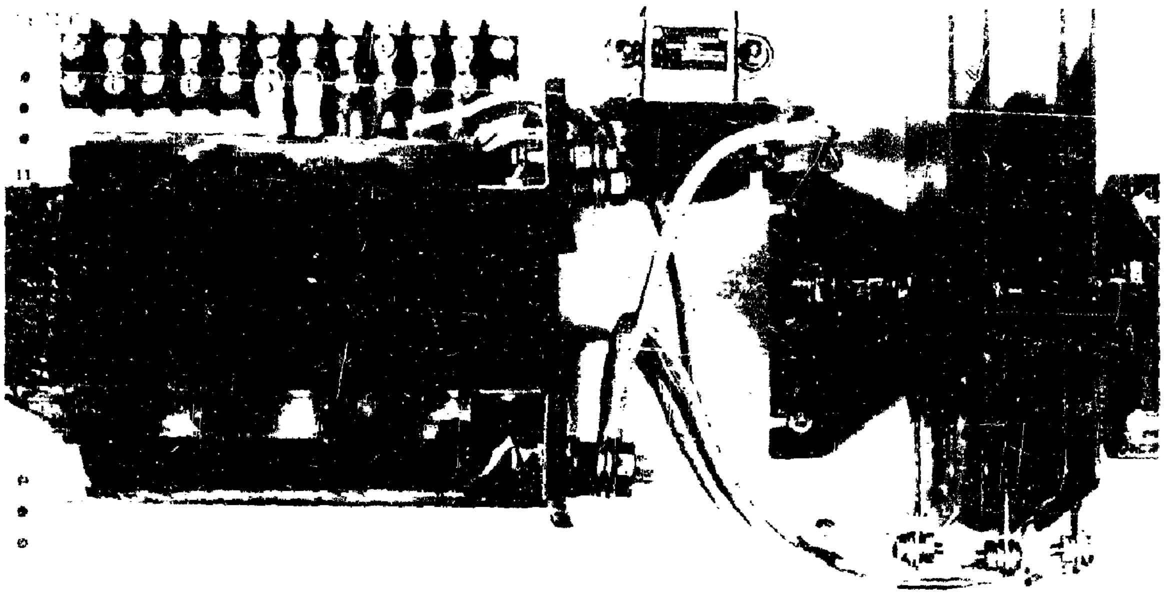


Fig. 18 - Saturable reactor power supply

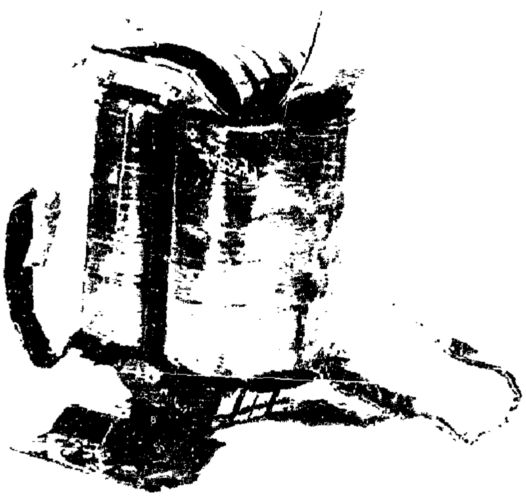


Fig. 19 - Twenty-kw power transformer (two per installation)

[5]NRL Memorandum Report No. 278, Confidential, dtd 31 March 1954

The voltage, current, and power supplied to the above transformer is metered by suitable panel instruments as shown in Fig. 20. The interconnections between these various units are shown in Fig. 16.

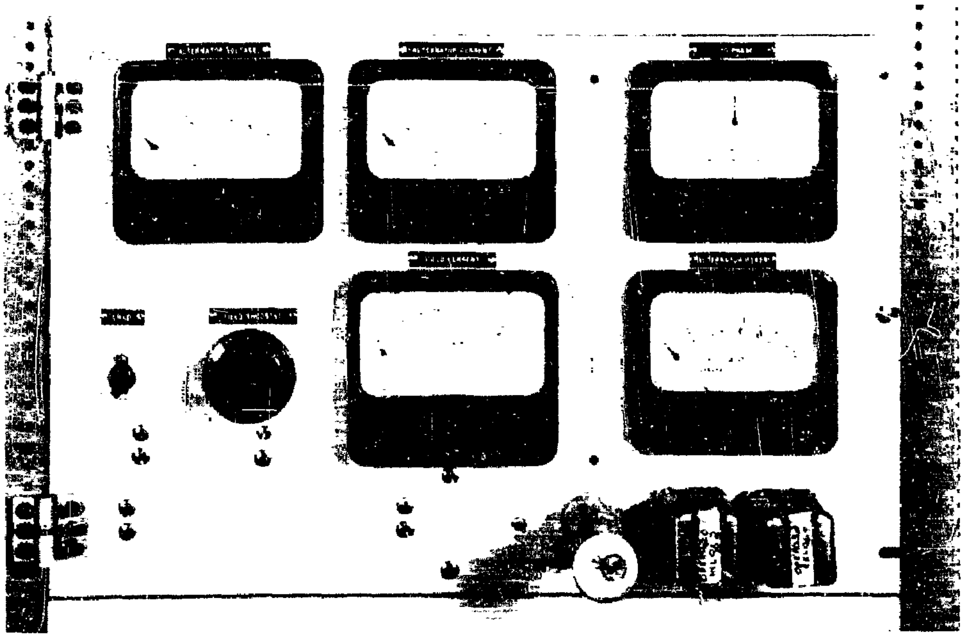


Fig. 20 - Meter panel

No voltage regulator is provided for the alternator. Consideration was given to such control; however, the long response time of the alternator field (3.9 seconds to reach 90 percent of steady-state field current) would not permit a regulator to stabilize the generator voltage in the one second allowed without the use of excessive swamping resistance. An unregulated system was provided, therefore, in which the field excitation was set to give the desired full-load voltage. Under this condition, the no-load voltage at the saturable reactor switch is approximately 50 percent above the full-load voltage; i.e., 300 volts at no load versus 200 volts at full load.

This high voltage presents no problem regarding the alternator and switch since they are both designed to meet the condition. On the other hand, the transformer was designed for a maximum secondary voltage of 1250 volts per unit. Therefore, the saturable reactor can be saturated only when the transformers are loaded with approximately 100 ohms.

STARTING CIRCUITS

It was desired that the power supply be designed to present the maximum simplicity in starting procedure. This was achieved through simple push-button controls for manual starting and stopping the Diesel engine.

The over-all operation of the circuits will be explained by outlining the sequence of events occurring when manual starting or stopping is initiated. All references will be made to the schematic diagram shown in Fig. 21.

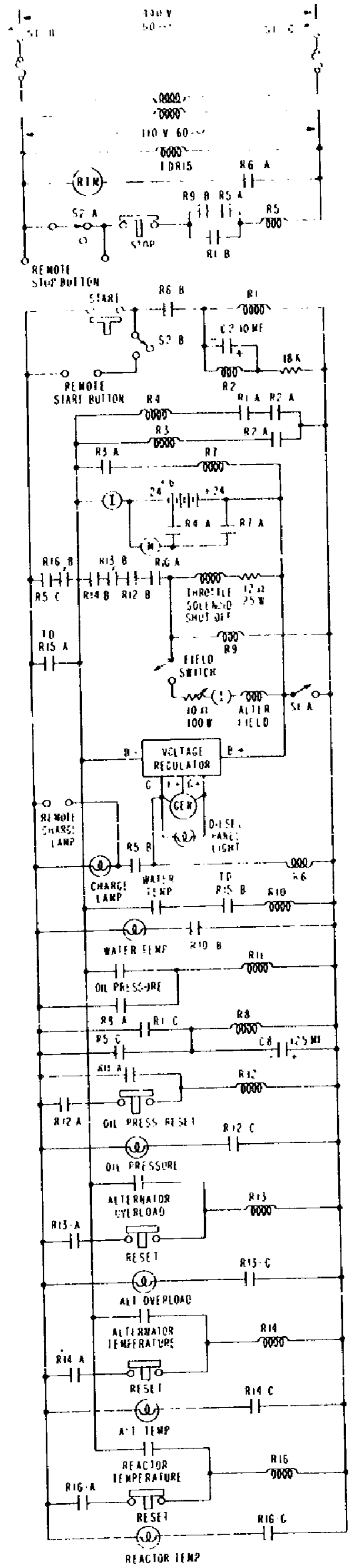


Fig. 21 - Starting and protective circuits

Prepare for Operation

Close switch S1.

S1-A supplies +24 volts dc to starting panel; S1-B and S1-C supply 440 volts ac to starting panel.

After two minutes, time delay relay TDR15 closes. Contacts TDR15-A and B supply -24 volts to starting panel and complete the cooling water "over-temperature" circuit,respectively.

Relays R12 and R8 are energized. Contact R8-A shorts out Oil Pressure contact (in preparation for starting) and energizes R11.

R11-A opens; however, R12 is held through R12-A and oil pressure reset button must be depressed to reset circuit.

R10 is energized, closing R10-A in the throttle shutoff and alternator field circuits and opening R10-B to the water-temperature pilot light.

Start Engine

Depress Start button and hold until charging light extinguishes.

Start contact energizes R1 and charges condenser C2.

R1-A energizes R4, supplying 6 volts to the starting motor, which engages the starting gears.

R1-B energizes R5 in the stop circuit.

R5-A closes to prepare a self-holding circuit for R5.

R5-B connects the charge lamp across the voltage regulator.

R5-C closes, supplying 24 volts to the alternator field circuit, completing the throttle shutoff circuit, which places the metering valve in position to give control to throttle servo motor, and energizing R9.

R9-A closes, supplying the reference frequency to the frequency divider. (See Figure 7.) R9-B closes in the stop circuit making R5 self-holding through R5-A.

C2 charges to pull-in voltage and energizes R2.

R2-A operates de-energizing R4 to remove the 6 volts from the starting motor and energizing R3 which, in turn, energizes R7 applying 24 volts to the starting motor.

When the engine starts and reaches approximately 1000 rpm, the charging lamp extinguishes as the generator builds up and R6 is energized.

R6-A energizes the Running Time Meter (RTM).

R6-B de-energizes R1 and R2. Start button may now be released.

R1-A and R2-A open, de-energizing the starting motor.

R1-B opens, transferring control of R5 to the self-holding circuit.

R1-C opens, removing 24 volts from R8, however, C8 holds R8 for a time sufficient for oil pressure to build up and close Oil Pressure contact.

Stop Engine

Depress Stop button momentarily.

Stop contact de-energizes R5, opens R5-C, and thus initiates engine shutdown sequence and disconnects alternator field.

Secure Equipment

Open switch S1.

Switch S1 de-energizes equipment.

PROTECTIVE CIRCUITS

In addition to manual stopping, it was desired to have automatic protective equipment for unattended operation. Protection was provided in the form of Diesel shutdown in the event of loss of a-c or d-c power, high temperature cooling water, low lubricating-oil pressure, high alternator temperature, high saturable-reactor temperature, excess alternator-load duration (current-time product), and excessive Diesel speed. The latter is integral with the Roosa-Master fuel pump and is described under the section on Prime Mover. All other conditions of faulty operation are detected by suitable means and, through appropriate circuits, shutdown the Diesel by de-energizing the shutoff solenoid on the fuel pump throttle.

Indicator lights are provided at the control panel to show proper operation of the battery charging generator and to provide an indication of the source of trouble in the event of shutdown due to casualty. Associated with the indicator lights and protective circuits, are reset buttons which are used to reset the circuit after a fault condition has caused shutdown. This arrangement provides the operator with information as to the cause of the casualty.

The automatic protective circuits will be explained with reference to Fig. 21.

High Water Temperature

Water temperature switch opens, de-energizing R10.

R10-A opens, initiating engine shutdown sequence.

R10-B closes, lighting Water Temperature pilot light.

When engine cools, depressing mechanical reset button on Water Temperature switch will place engine in condition for starting.

Loss of Oil Pressure

Oil Pressure Switch opens, de-energizing R11.

R11-A closes, energizing R12. R12-A closes, holding R12.

R12-B opens, initiating engine shutdown sequence. R12-C closes, lighting Oil Pressure pilot light.

When cause of oil pressure drop is found and corrected, depressing Oil Pressure Reset button will place engine in condition for starting.

Overloaded Alternator

Alternator Overload switch closes energizing R13.

R13-A closes, holding R13.

R13-B opens, initiating engine shutdown sequence.

R13-C closes, lighting Alternator Overload pilot light.

Several seconds after overload switch closes, it automatically opens, at which time Alternator Overload Reset button may be depressed placing engine in condition for starting.

High Alternator Temperature

Alternator Temperature switch closes, energizing R14.

R14-A closes, holding R14.

R14-B opens, initiating engine shutdown sequence.

R14-C closes, lighting Alternator Temperature pilot light.

After alternator cools, the temperature switch will open and depressing Alternator Temperature Reset button will place engine in condition for starting.

High Reactor Temperature

Reactor Temperature switch closes, energizing R16.

R16-A closes, holding R16.

R16-B opens, initiating engine shutdown sequence.

R16-C closes, lighting Reactor Temperature pilot light.

After reactor cools, the temperature switch will open, and depressing Reactor Temperature Reset button will place engine in condition for starting.

The controls made available to the operator, which include pilot lights and other equipment, are shown in Fig. 22 as arranged on the control panel. A separate station can be provided to start the Diesel from a remote point and will have only the charge light and start-stop buttons.

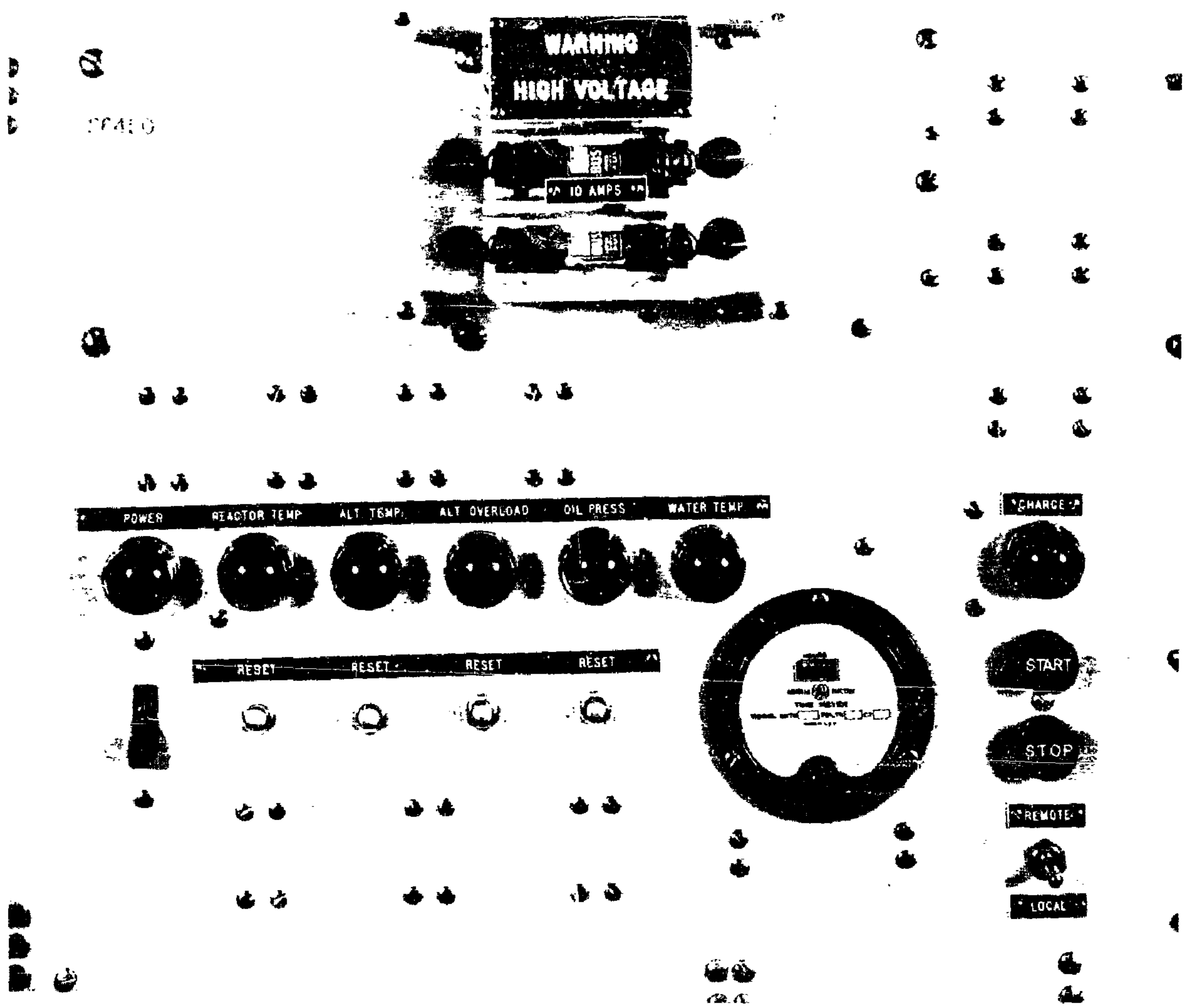


Fig. 22 - Control panel

CHARACTERISTICS OF THE ROTATING-MACHINERY POWER SUPPLY

The components as described above were integrated to give a 5000-cps 40-kw power supply having the following observed performance characteristics;

Output Power -	40 kw at transformer output terminals, 2000 volts, single phase.
Wave Form -	Less than 5% distortion.
Frequency	5000 cycles per second, adjustable over a range of plus 300 and minus 500 cycles per second and controlled to an accuracy of plus and minus 2.0 cycles of the reference frequency.
Transient Response -	Frequency is stabilized to within ±2.0 cycles of the reference frequency within 0.7 second after step application of full load. Maximum frequency deviation during this step load is approximately 2%. Voltage deviation is directly proportional to frequency deviation.
Duty Cycle -	Maximum duty cycle is 8 seconds, 3 seconds full load, 5 seconds no load. The permissible duration of on time can be increased by addition of forced air cooling of the alternator, transformer, and saturable reactor switch.

The physical characteristics of the power supply are as follows:

Diesel-Alternator -	3984 pounds; 40″ wide x 99″ long x 48″ high.
Control Racks -	600 pounds; 14″ wide x 60″ long x 60″ high; 24″ x 72″ floor space.

The characteristics of the frequency control are indicated in Fig. 23, which is a representative load cycle showing generated frequency versus time. The initial load application transient shows a maximum frequency shift of 110 cps with the major transient subsiding one-half second after the load was applied. During the two-second steady-state period, the maximum frequency deviation is -2, +1 cycles. This response represents an average curve, since some load cycles may have a steady-state error of less than ±0.5 cps and others may deviate as much as ±2.0 cps.

The requirement of holding desired frequency to within plus or minus one cycle per second has been interpreted to require the total number of cycles occurring during a one-second interval to be numerically equal to the desired frequency within one cycle, and also to restrict the allowable rate of frequency deviation. Therefore, the power supply was designed to hold the rate of frequency deviation as close as practicable to the figure of one cycle per second per second. It is to be noted in Fig. 24 that the average rate of frequency deviation for the one-second interval prior to removal of the load is approximately 0.8 cycle per second per second. The maximum rate of frequency deviation averaged over several load cycles is approximately 2 cycles per second per second. Long-time (tens of seconds) frequency deviation would approach zero as a result of the action of the integral control.

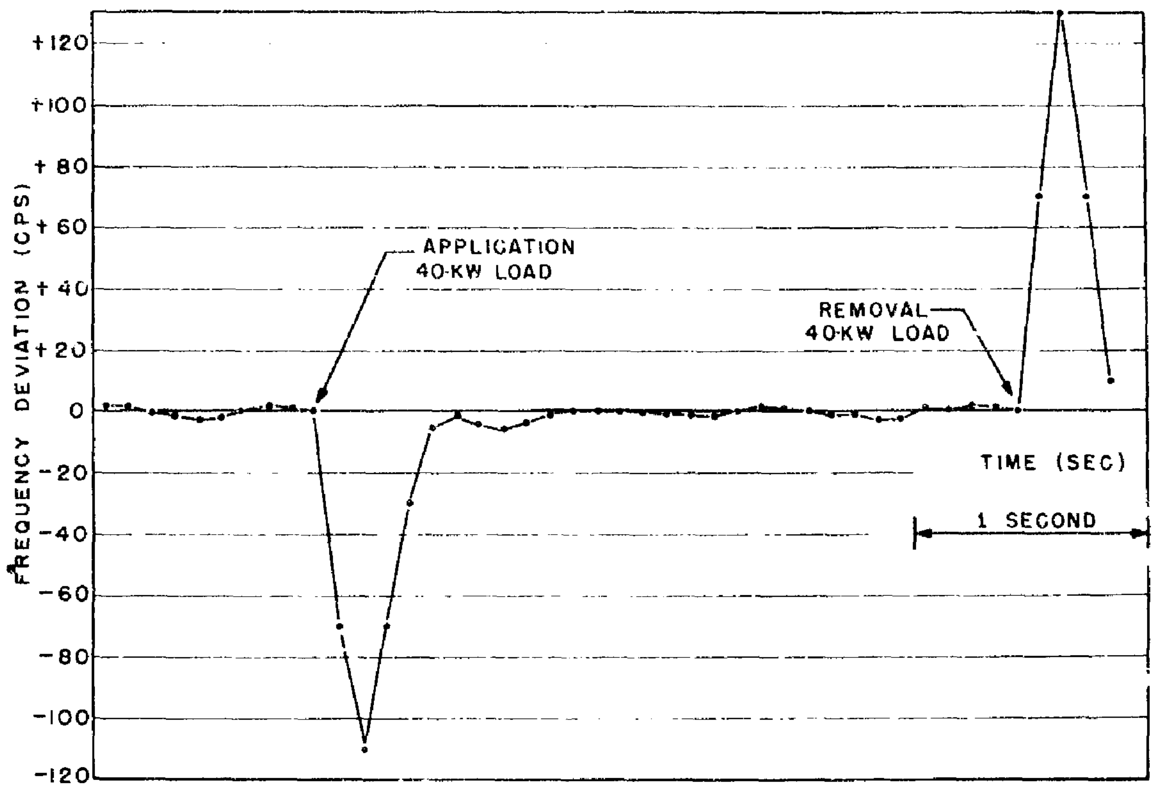


Fig. 23 - Response characteristic, LRS power supply

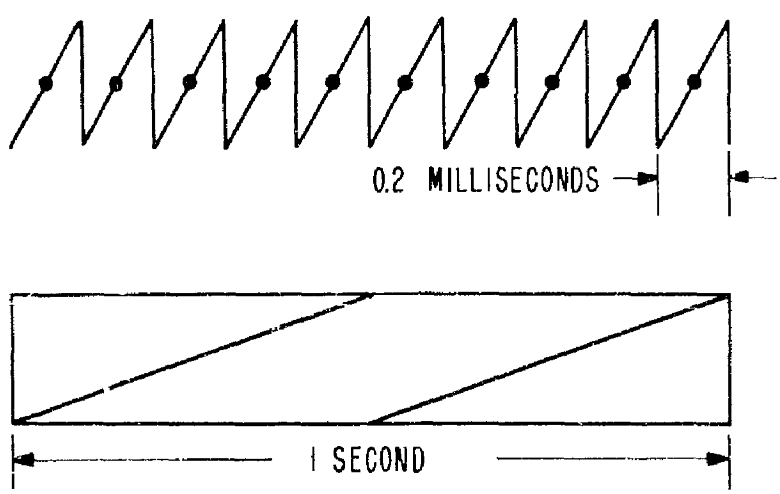


Fig. 24 - Phase versus time plot

System adjustments are critical for optimum performance, but over a period of more than three weeks of eight hour operation daily with no change in adjustments, the system continuously provided acceptable performance.

SUMMARY

A Diesel engine - alternator power supply has been designed to furnish a 40 kw load at a frequency of 5000 cycles per second. The peak deviation with step application of full load is less than 2% and frequency stabilization is obtained after a one-second transient interval. The stabilized frequency taken over a two-second interval has a maximum rate of deviation of two cycles per second per second.

* * *

APPENDIX A
Measurement of Frequency Deviation

The specified accuracy of frequency for the rotating-machinery power supply raised the problem of means for accurate measurement of power-supply frequency. Two approaches are possible: one would be to measure the frequency directly, the other would involve the comparison of the power-supply frequency with the reference oscillator. The latter method, utilizing comparison of the reference frequency and the output frequency, is more desirable in that it avoids extreme resolution in the measuring instrument. A method of measurement is herein described which satisfies these requirements by presenting a plot of phase-angle deviation between reference and generated frequencies versus time. Frequency deviation of the system is then obtained by differentiation of the phase-angle plot.

The principle of measurement is to provide an oscilloscopic presentation consisting of a raster formed by vertical sawtooth deflections at reference frequency and horizontal time-scale deflections at an arbitrary low repetition rate. Intensity modulating pulses brighten the raster at a fixed phase of generated frequency. The resultant trace is a time plot of phase deviation of the generated frequency relative to the reference frequency as indicated by intensity modulation of the vertical reference phase scale. Figure 24 demonstrates the basic display as viewed with an expanded time scale when generated frequency is equal to reference frequency and has phase angle deviation of 180^0. The lower figure shows the loci of points resulting from intensity-modulating pulses for a 2.0 cps difference between reference and generated frequencies taken over a one-second interval. It can be seen that the slope of the phase plot is proportional to the frequency deviation of generated frequency relative to reference frequency.

Figure 25 is a photograph of power supply response to a step-type load as presented by the phase plot. The photographic record was obtained by applying the reference frequency sawtooth to the horizontal deflection plates, no signal to the vertical plates, intensity modulating as before, and utilizing a Fairchild oscilloscope camera which takes a photograph on a moving 35 mm film strip. The motion of the film strip serves the same function as the horizontal time base mentioned above. Differentiating this phase plot will give a frequency-deviation curve similar to that shown in Fig. 23.

Figure 26 is a schematic diagram of the oscilloscope used to measure frequency deviation of the rotating-machinery power supply. The vertical sweep amplifier converts the sinusoidal reference frequency to a sawtooth wave and applies this voltage to the oscilloscope vertical-deflection plates. The horizontal sweep oscillator provides a 1.0 cps time base to the horizontal-deflection plates. Thus a raster is formed on the cathode-ray tube. The intensity modulator converts generated frequency to a pulse train and applies this pulse train to modulate the cathode ray thus brightening the raster. The front and rear view of the cathode-ray indicator is presented in Fig. 27.

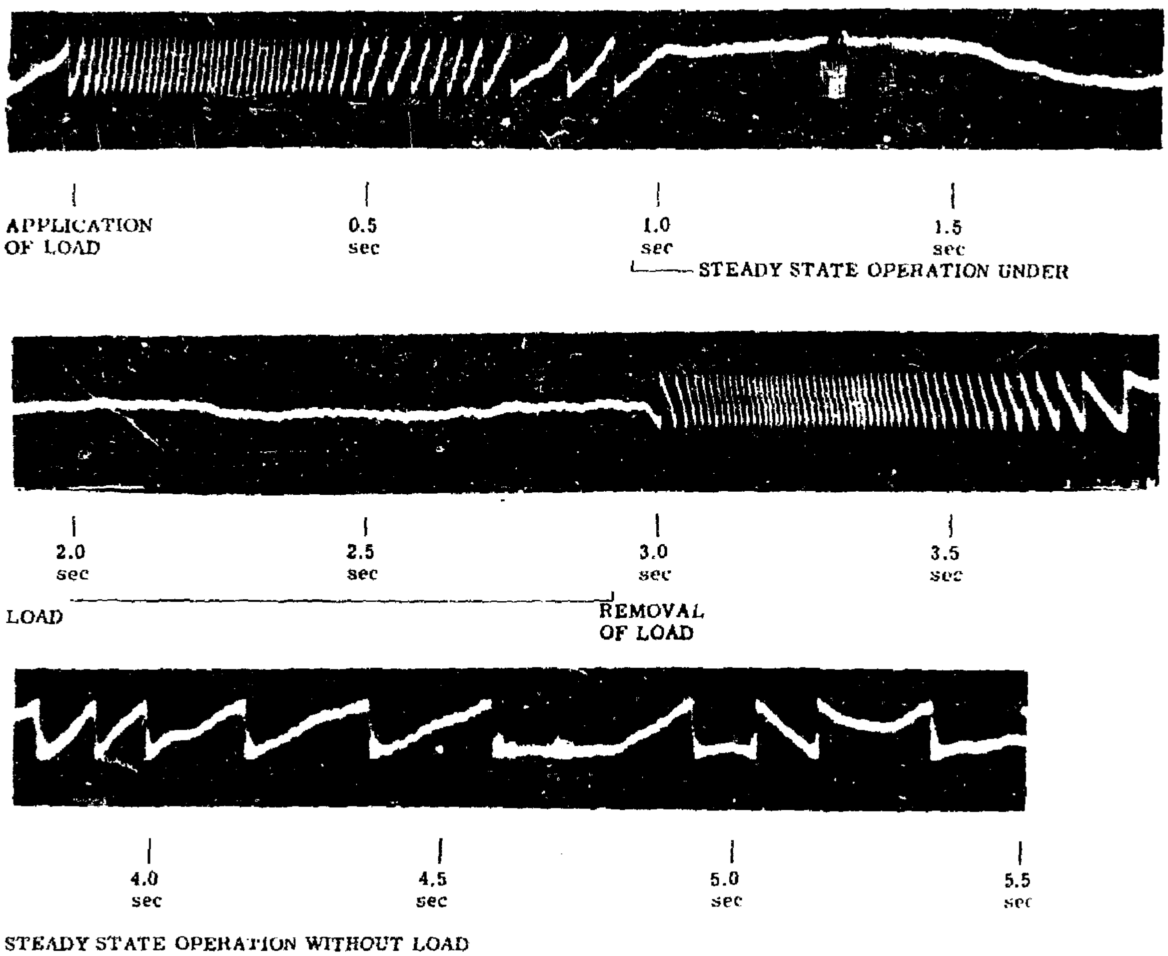


Fig. 25 - Oscilloscope presentation

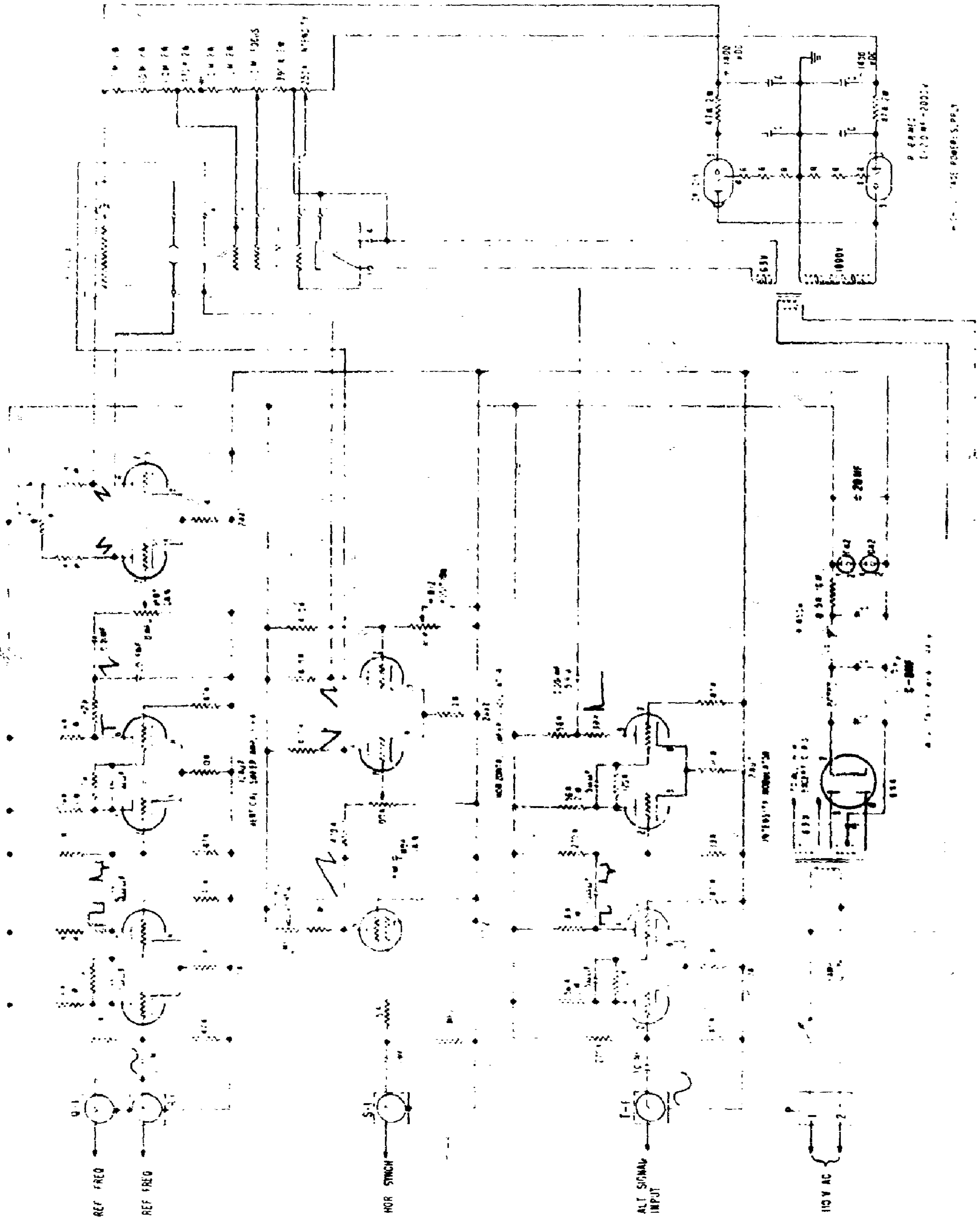


Fig. 26 - Cathode-ray indicator circuit

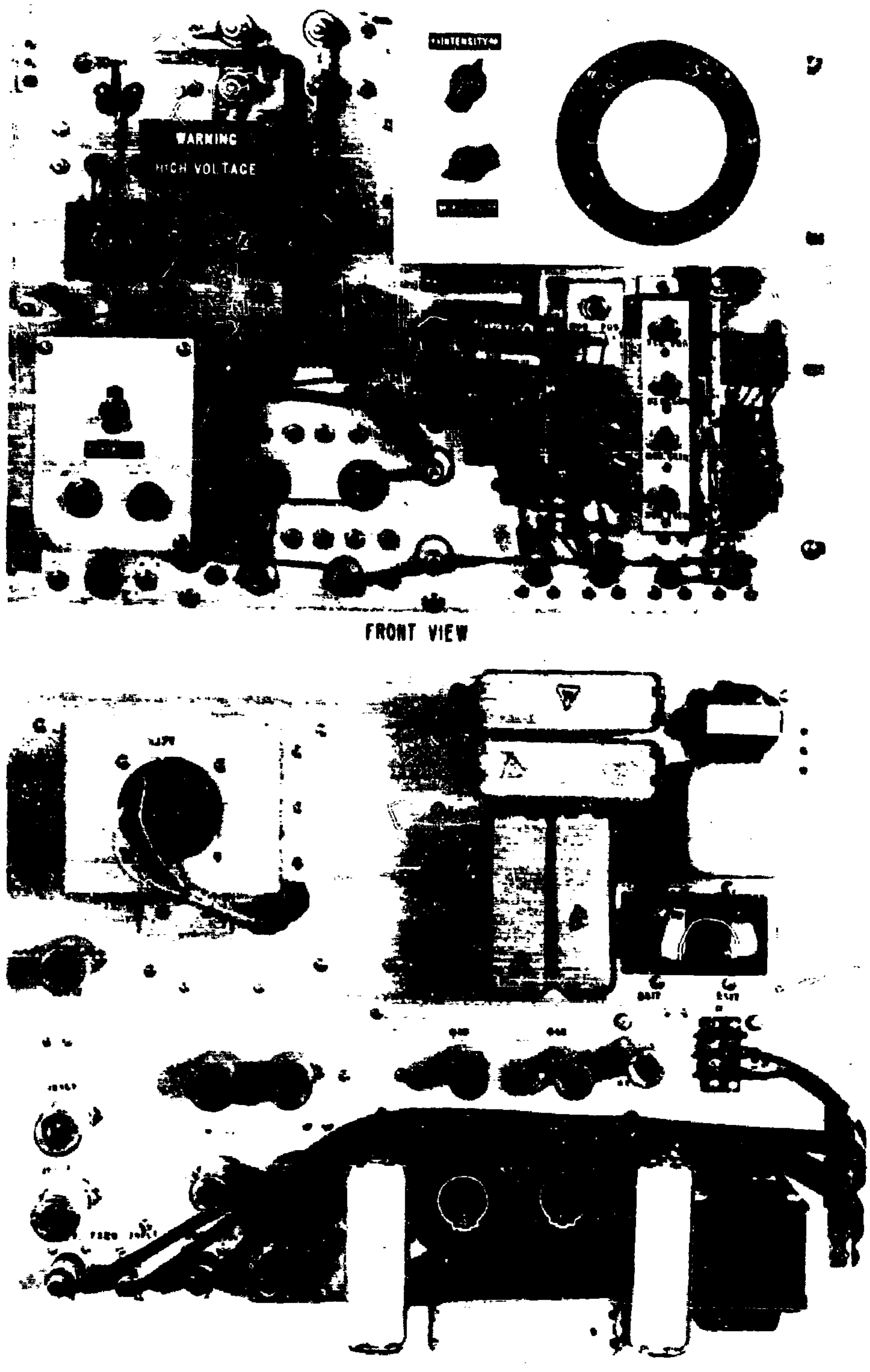


Fig. 27 - Cathode-ray indicator (front and rear views)

* * *

UNITED STATES GOVERNMENT

memorandum

7103/107

DATE: 7 October 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

AD-033 730

VIA: Code 7100

REF: (a) NRL Confidential Report #4368 by A.T. McClinton, et al (U)
(b) DoD Dir. 5200.10

1. Reference (a) is a report on the development of a power supply for an experimental long-range sonar. It is a 40kw, 5,000 cycle per second diesel-driven alternator with a speed regulator controlling the diesel speed within 0.08%.

2. The technology and use of this development has advanced to the point so that this report is only of historic interest.

3. Reference (a) was declassified by reference (b).

4. Based on the above, it is recommended that reference (a) be released with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

Edward R. Franchi 10/7/96

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

Completed
2-7-2000
B.W.

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